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ABSTRACT

While most present research suggests that visual information acquired from peripheral visual areas on one fixation during reading facilitates the identification of words available on the next fixation, some researchers hold with the "word unit hypothesis," which suggests that information gained peripherally from a word on one fixation does not facilitate its processing on the next. In a study conducted to discover whether peripheral facilitation was taking place during reading, 16 college students read short texts on a cathode-ray tube as their eye movements were monitored. As they read, the contents of certain word locations changed from fixation to fixation, alternating between two words differing in two letters. The results indicated that the words were read only when directly fixated, and that there was no facilitation from prior peripherally obtained information about the words, thus supporting the word unit hypothesis of information processing. (FL)

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CENTER FOR THE STUDY OF READING

Technical Report No. 243

PERCEIVING WORDS DURING READING: LACK OF FACILITATION FROM PRIOR PERIPHERAL EXPOSURE

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Abstract

College students read short texts displayed on a cathode-ray tube as their eye movements were being monitored. As they read, the contents of certain word locations changed from fixation to fixation, alternating between two words differing in two letters. This manipulation had no effect on reading unless the subjects happened to regress to or reread the word later. The results indicated that these words, which were low in contextual constraint, were read only when directly fixated, and that there was no facilitation from prior peripherally-obtained information about the words.

Perceiving Words During Reading: Lack of Facilitation from Prior Peripheral Exposure

Present evidence suggests that visual information acquired from peripheral visual areas on one fixation during reading facilitates the identification of words available foveally on the next fixation (McConkie & Rayner, 1976a; Rayner, 1975; Rayner, 1978). While there are many possible mechanisms by which such facilitation might be achieved, for present purposes these can be divided into two broad categories. First, it may be that words are often perceived in sub-word units (letters, letter groups, syllables, etc.), with one or more sub-units of a word being perceived on one fixation and the remainder on the next (McConkie, 1979). Thus, words may be identified from subparts which are frequently obtained on different fixations. This position will be referred to as the sub-word unit hypothesis. It would suggest that parts of a word perceived on one fixation are not reprocessed on the next, and that the individual fixation span (Underwood & McConkie, Note 1), or the region perceived during a fixation, does not necessarily extend to word boundaries.

A second way in which peripherally obtained information might facilitate processing of the foveal stimulus on the next

fixation will be referred to the information accrual hypothesis. This assumes that the stimulus pattern, while lying too far into the periphery to support word identification, has still been partially processed, and the information gained facilitates word or meaning identification on the next fixation. For instance, it may be that certain features of a word, such as its general shape or length, or features of some letters in the word, have been obtained, or that some sort of preprocessing has permitting priming of the lexical entries of a word set which includes the correct word, on the basis of semantic or phonological information, for instance. In general, this hypothesis assumes that the information obtained is not the identification of subparts of the word (letters or orthographic units), but is more general information that places constraints on what the word might be. Admittedly, the distinction between these two hypotheses becomes difficult if one thinks of features of words or letters as being subparts of those units, but this will not cause difficulty in the context of the present study.

The other possibility, of course, is that information obtained peripherally from a word on one fixation does not facilitate its processing when it comes into the foveal region for the next fixation. This could occur either because such visual analysis of peripheral words is not attempted during

fixations in reading, or because when identification of a word fails, all information accumulated about it is discarded, and processing begins anew on the next fixation. This would require that words typically be identified only from the visual pattern present during a fixation, without the use of information obtained during prior fixations. There would certainly have to be exceptions to this, as when words are split between two lines or two pages, or when a word is so long as to require more than one fixation to perceive it. These conditions would necessitate the additional ability to perceive and use subparts, such as syllables or the parts of compound words. However, it would assume that this is not normally the way perception proceeds in skilled reading. This position will be referred to as the word unit hypothesis, since it assumes that entire words are typically identified during a single fixation, rather than perceiving subparts or accruing information about them to use later.

Present evidence favors the peripheral acquisition of information, and thus stands against the word-unit hypothesis, though it is unclear whether this facilitation occurs in an information accrual or sub-word unit manner. Having erroneous letters in the periphery during one fixation can inflate the duration of the next fixation, when that region is brought into foveal vision, even though the errors have now been replaced by

normal text (O'Regan, 1980; Rayner, 1975; Underwood & McConkie, Note 1). In addition, Rayner (1975) found that if a word is changed during the saccade taking the eyes to that location, some disruption results, even when both words are appropriate to the context. Similarly, in a word-naming task, having a word in the periphery during one fixation reduces the time required to name in when it is in the fovea on the next fixation (Rayner, 1978; Rayner, McConkie, & Ehrlich, 1978), though this facilitation may depend on subjects' familiarity with the word set used, or on the degree of contextual constraint operating (McClelland & O'Regan, 1981; Paap & Newsome, 1981). These results have been taken as support for the notion that information obtained peripherally on one fixation is brought to bear in the perceiving of those words on the next fixation. The information carried across is apparently not strictly visual in nature (McConkie & Zola, 1979) and there is some evidence that it may not be semantic or phonetic (Rayner, McConkie, & Zola, 1980). However, these studies have failed to indicate whether the information obtained peripherally was of sub-word units (McConkie, 1979) or more general information accrual. One study suggests that it may be sub-word units that are acquired, though the task used was one of naming words rather than more normal reading (Rayner, McConkie, & Zola, 1980).

The present study attempted to investigate, in a more controlled manner, whether peripheral facilitation was taking place during reading, and more importantly, to do this in a way which would allow a choice between the sub-word units hypothesis and the informational accrual hypothesis as an explanation for any observed facilitation. In order to do this, sets of four words were identified which differed in only two letters (for example, pears, bears, peaks and beaks). Sentences were then written which contained one word location in which any of the four words could appropriately fit. Subjects read these sentences, displayed on a cathode-ray tube (CRT) under computer control, as their eye movements were being monitored. As they read, during saccades in the region around the critical word location, the display was changed between two of the words which differed in both letters (for instance, between bears to peaks). Thus, the word in that location alternated between two of the possible words on successive fixations. If the sub-word units hypothesis is an accurate description of perception during reading, there should be times when the subjects acquire the first letter of the word during one fixation and the fourth letter during the next, thus perceiving a word which was in fact never present on the CRT (beaks or pears in the above example). This could well occur without any evidence of disruption in the

eye movement pattern, since the reader would likely not know the word had changed. Any combination of letters perceived as the word changed would result in an appropriate reading of the sentence. On the other hand, if perception occurs by an information-accrual process, then the change of the pattern in that word position from one fixation to the next should produce disruption in reading, as found in prior studies, but it would be unlikely that the reader would report seeing words that were never actually on the CRT. Finally, if subjects showed no evidence of disruption from the changing letters, and also failed to perceive words not present on the CRT (but constructed from parts of words which were present), this would be taken as evidence for the word-unit hypothesis.

METHOD

Subjects

The subjects were sixteen University of Illinois undergraduates who had normal, uncorrected vision, were native speakers of English, and were paid for their participation in the experiment. All the subjects had previously participated for four to six hours in another experiment involving the same general type of task.

Materials

Twenty-five quadruplets of five-letter words were chosen such that each word in a set differed from one of the other words in only the first letter, from a second word in only the fourth, and from the remaining word in both the first and fourth letters. For each quadruplet, a short text of one to three sentences was constructed which made sense when any of the four words occupied a particular word position, to be referred to as the critical word location. These texts are presented in the appendix. In addition to these texts, eight others of similar length and style were used for warm-up and filler sentences.

Apparatus

The text was displayed one line at a time on a Digital Equipment Corporation Model VT-11 CRT. The CRT has a P-31 phosphor which decays to 1% of the original intensity in 500 microseconds and a hardware character generator capable of producing upper and lower case letters. The display was refreshed every 3 msec. Thus display changes can be made within 3 msec without interrupting the refresh cycle. The CRT was 68 cm. away from the subject, which made one degree of visual angle equivalent to 4 character positions. The subject was supplied with a button which called the next line of text onto the CRT.

Eye movements were monitored with a SRI Dual Purkinjie Eyetracker. The procedures currently used maintain an accuracy within a quarter of a degree of visual angle. Only the horizontal channel of the eyetracker was monitored. The CRT and the eyetracker were interfaced with a Digital Equipment Corporation PDP-11/40 computer, which was programmed to sample eye position every msec and to make display changes at certain times when the eyes were identified as being in a saccade.

Procedure

Subjects were fitted with a bite bar and head rest in order to minimize head movement. The thirty-three texts were split into two groups with a short rest in between. Before and after reading each group, subjects were engaged in a calibration task, in which they successively fixated on five dots placed at equidistant points on the CRT on the line on which text was to be displayed. As each dot was fixated, the subject pressed a button, which caused the computer to sample the voltage level of the eyetracker for that position. These values were used to translate eyetracker voltage levels to eye position locations on the CRT while the subject was reading. Values obtained before and after reading each group of texts were compared to judge the accuracy of the data.

While subjects read each text, display changes occurred during saccades made in the region of the critical word. The display change consisted of substituting one line of text for another while the eyes were in a saccade. In the experimental condition, the substituted line of text was the same as the original except that the first and fourth letters of the critical word had been changed, replacing the word with its alternative. So, for successive fixations in the vicinity of the critical word, two words differing in two letters alternated from one fixation to another. For example, if on one fixation the word blame were present, on the second flare would be present, on the third blame would be present, on the fourth flare, etc. (where the actual switching was occurring during the saccades between the fixations). In the control condition, the substituted line of text was identical to the original line, so that on each fixation the same alternative was present.

The region within which this switching occurred was defined in the following manner. Three boundaries were set on each line containing a critical word location. The first, the enabling boundary, was always 11 character positions to the right of the beginning of the line. No display changes were permitted until the eyes had fixated at least once to the left of that boundary. The second, the initiating boundary, was 18 character positions

to the left of the critical word location, or one position to the right of the enabling boundary if it were 18 or fewer character positions to the left of the critical word location. The first display change occurred during the saccade following the first fixation to the right of the initiating boundary, given that the eyes had previously fixated left of the enabling boundary, and the word changed during each following saccade until terminated by one of two possible events. The third boundary, the terminating boundary, was 11 character positions to the right of the first letter of the critical word location. Display changes were permanently disabled for a given line following the first fixation to the right of the terminating boundary, or following the first regressive saccade, after such changes had been initiated. Thus, display changes occurred only during saccades following fixations that lay between the initiating and terminating boundaries. Within this region, they occurred only if (a) the enabling boundary had previously been crossed, (b) no previous regressions had been made since entering the region, and (c) this region had not been previously read (that is, the initiating and terminating boundaries had not previously been crossed, in that order). With this algorithm, the decision as to whether a display change should occur during a saccade was made during the prior fixation, making it possible to insure that all

changes took place early during the saccade, and none occurred at or after the time the eyes were coming into a fixation.

After reading each text the subject was presented with each of the words in the quadruplet relevant to that text, one at a time. The order of these test words was randomized for each text. The subject was instructed to indicate whether each test word had been present in the text. The subject was supplied with two buttons, one to indicate yes and one to indicate no. Note that in each test set for texts in the experimental condition, two words had actually been in the text and the other two had not. In the control condition, only one of the four words had been present during reading.

Each subject received the texts and test items in the same order, but the order of assignment of conditions to texts was counterbalanced across subjects. Subjects were divided into eight groups. Groups 1 to 4 had thirteen experimental and twelve control texts. For groups 5 to 8 the conditions to which the texts were assigned were reversed, resulting in twelve experimental and thirteen control texts. Groups 1 to 4 each had a different word in the critical word location when the text initially appeared; similarly for groups 5 to 8. The initially-appearing word was the only word present in the control texts; in

the experimental texts the contents of the critical word location alternated between the initially-appearing word and the word created by changing both the first and fourth letters. Thus, the conditions, texts and word alternatives were all counterbalanced with respect to each other.

Results

The results will be reported as providing answers to four questions. First, how accurate were the subjects' responses on the test items? Second, did the subjects report seeing words that were never present as they read under the experimental conditions? Third, within what region were the critical letters perceived? Fourth, did the letter changes that were taking place cause interference (or reduce normal facilitation) during reading?

Accuracy of the Subjects' Responses

The different patterns of responses to the test items, together with the frequency with which each occurred, are shown in Table 1. An examination of the response patterns for the texts read under the control condition, where the same word always occupied the critical word location, indicates that 85% of the time the subjects reported seeing only the word actually

present in the text. On another 5.5% of the instances they chose the correct word plus another word, on 3.5% they selected no word, and on the remaining 6% they chose a wrong word, one not in the sentence.

Insert Table 1 about here.

Of the 23 instances on which an erroneous word was selected, on 22 the selected word shared one letter with the original. Only once did a subject choose a word differing in both letters. Thus, even when a wrong word was reported, it tended to maintain information from the original word. In the 12 instances in which a single erroneous word was selected, it shared the first letter with the original word 4 times, the fourth letter 7 times, and neither letter only once. Thus, there was no tendency for the first letter to be maintained more frequently than the fourth, as might have been expected. Finally, it should be noted that in every case in which an error was made (including selecting none of the test words) the subject's eyes had been centered on the critical word on at least one fixation. The errors did not arise from physically skipping over the word.

In general, then, subjects were quite accurate in selecting the word that was in the text in the control condition, though some errors were made.

Frequency of Selecting Non-presented Words in the Experimental Condition

Table 1 gives the frequencies with which subjects reported having seen words which were never present on the CRT as they read. While this occurred more frequently under the experimental condition than under the control, this difference was small (31 vs. 23) and not statistically significant. Thus, it appears that these 5-letter words were seldom if ever being perceived from sub-units acquired on two successive fixations. In the experimental condition, as in the control, most of the time the subjects reported having seen one of the words that was present in the text as they read.

The Region Within Which the Letters Were Being Identified

In order to obtain a general indication of the region within which the eyes were centered when the critical word was being read, experimental condition instances were selected in which the subject (a) made a single correct response, and (b) showed no regressions and no refixations following a regression in the

region around the critical word (from 10 letter positions prior to it to 5 letter positions following it), and in which (c) the letter was switching during saccades and (d) the equipment was tracking the reader's eyes properly. This yielded a total of 73 unambiguous cases. All fixations on these sentences between 15 letter positions to the left of the critical word and 6 to the right were then classified according to (a) their location with respect to the critical word, and (b) whether or not the word present during that fixation was the one reported as having been seen. These data are plotted in Figure 1. The solid line indicates the total number of fixations centered at each letter position. There is a maximum at the location of the critical word with minima to either side, reflecting the tendency of subjects to fixate the centers of words (O'Regan, 1981; Rayner, 1979a; Zola, 1981). This maximum does not necessarily reflect any tendency to fixate the critical word more than other words; it simply reflects the fact that the data are grouped with respect to the position of that word. No such consistent correspondence exists for other words across the passages when the data are grouped in this manner.

Insert Figure 1 about here.

The data of interest are the frequencies with which the word present during fixations at different locations was the word reported as being seen. Each such fixation is a candidate for being the fixation on which the word was identified (though, of course, this does not mean that the word was identified on all these fixations). The frequencies of these fixations are shown in the dotted line on Figure 1. As can be seen, in every instance but one where a fixation fell directly on the critical word, the word present on that fixation was reported as having been seen. Of 11 fixations on the space prior to and following the word, the word reported as being seen was present on 6 of those fixations. And during fixations on the five locations before or after the word (including spaces before and after), the word reported was present on only 5 of the 88 fixations. In each of these latter cases, there was another fixation directly on the critical word or on the space before or after, on which the reported word was present. Thus, it appears that the critical word was being identified only on fixations directly on that word, or sometimes on the space before or after. Apparently, whether the first or fourth letter of the critical word location was being employed in word perception during a fixation depended less on the location of that letter with respect to the fixation location (that is, on how many letter positions it lay to left or

right of the center of vision), and more on whether the word containing it was directly fixated. The data include instances in which the fixation was centered on the 5th letter of the word, and even on the space following it, thus placing the first letter of the word 4 or 5 letter positions to the left of the fixation point, on the fixation on which the word was identified. That initial letter of the word could not have been acquired on the prior fixation, because a different letter had occupied the location on that fixation. Likewise, there are other instances in which the eyes were fixated just 1 or 2 letter positions to the left of the initial letter of the word, and that letter was apparently not picked up, in spite of prior evidence suggesting that the perceptual span tends to be asymmetric to the right (McConkie & Rayner, 1976b; Rayner, Well, & Pollatsek, 1980; Underwood & McConkie, Note 1).

It appears, then, that when these readers were making a rightward series of saccades along a line of text, the region influencing word perception during a fixation was defined in terms of word units, rather than in terms of a certain number of letters to right and left of the fixation point. If a word was fixated only once (as was typically the case in these data) that fixation was typically the one which provided the visual information for the perception of that word.

The data from those instances on which a subject regressed back to the critical word or reread the region containing the critical word after having regressed to an earlier region were also examined. In these instances, during most of the fixations on the word, the word reported as having been seen was present. This was typically the case because of the letter switching algorithm used. When a subject regressed, the word was changed, but further changing was discontinued. Thus, if the subject made a fixation on the word, went one fixation beyond, and then returned to the word for several fixations, the fixation following the regression and all further fixations would have the same word present as was present on the initial fixation on the word. In spite of this aspect of the study, there were 53 instances in the experimental condition in which subjects had fixations centered directly on the critical word or on the space before or after, during which each of the two words were present. An examination of the responses made following these sentences indicates that a single correct response was given 36 times, or 68%. Both words were reported 3 times, a correct plus 1 or 2 incorrect words 6 times, only an incorrect word 3 times, and no response 6 times. Thus, most of the time when a word was refixated after it had been changed, only one of the words was reported as having been seen, and the frequency of reporting both

was less than that of reporting a correct word and an erroneous one. While further research is needed to investigate the possibility that subjects were not always reporting all the words they actually saw, it appears possible that, when regressions or rereadings are involved, it is not necessarily the case that a word is being identified each time it is fixated. Such a finding would raise questions about the function of such fixations, but the present data provide no additional information on this issue.

Effect of Changing Letters on Reading

Several aspects of the data indicated that changing letters from one fixation to another was producing an effect on reading. The total number of fixations on the critical word was 387 in the experimental condition, as opposed to 314 in the control. The mean duration of fixations falling in the region from 5 letters prior to, to 5 letters following, the critical word was 266 msec as compared to 254 msec for the control condition.

In order to provide unambiguous evidence concerning the effect of changing letters, the data were searched for those instances on which the first fixation on the critical word was preceded by a saccade during which the letters in the critical word were changed. Data from the control condition were selected in an identical manner, since the same algorithm had been used in

controlling the display in that condition. This produced a data set of 157 instances in the experimental condition and 151 in the control condition. The first fixation on the word was labeled fixation F0, the saccade following it, saccade S1, and the next fixation, fixation F1. For each subject, the mean F0 and F1 fixation durations, and the mean S1 saccade length were calculated for those experimental and control sentences which met the above criteria. Means for the experimental and control conditions were then calculated by averaging the subject means. These were compared by t-test for correlated means. The results are presented in Table 2, which indicate that no detectable effect was observed on either fixation F0 or saccade S1, but that a marginal effect may have been present on fixation F1. Further analysis indicated that this latter effect disappeared after removing all F1 fixations that followed regressive S1 saccades, or those that were centered on the critical word location (these being the second fixation on the word, and typically being preceded by a regression). Finally, as Table 2 shows, when the F1 fixations were subdivided into those which fell to the right of the critical word, and those which fell on or to the left of it, a significant effect was found only for the latter. It appears, then, that the F1 fixation durations only showed an effect when regressions and/or refixations of the critical word

were involved. It should be noted that these were cases in which the word changed again during saccade S1, so the word was different on fixation F1 than it had been on F0. It seems quite likely that this effect on fixation F1 was actually due to this second change, rather than the first. Thus, there is no evidence that having a different word present during the fixation prior to that on which the word was directly fixated had any effect on processing that word. It appears that the change in the word only has an influence on some instances when a second fixation is made on the word, or when there is a regression on the following saccade.

Insert Table 2 about here.

Finally, it seemed possible that the display change only influenced reading when the fixation prior to the fixation on the critical word location was close enough to it that visual detail could be resolved. To test this, the data were split into those instances in which the fixation prior to fixation F0 was less than 5 character positions to the left of the critical word location, and those in which it was 5 or more character positions to the left. Mean F0 fixation durations for experimental and

control conditions in the first of these cases were 287 and 276 msec; in the second case they were 278 and 264 msec. Neither of these differences was significant ($t < 1$ and $t = 1.39$, $p = .09$, successively) and there was no evidence for the predicted interaction.

As reported earlier, in the total data set there were more fixations in the region of the critical word in the experimental condition than in the control (from 5 character positions before to 5 after the word) and these fixations show slightly longer durations in the experimental condition. Once again, when these data are partitioned into first pass fixations (those taking the eyes further along the line than they had previously been) and those involving regressions and rereadings, the difference is only found in the latter set. Mean fixation durations for first pass data are 258 vs. 257 msec for experimental and control conditions, respectively; corresponding values for the other set are 283 and 245 msec.

It seems evident, then, that the effects of changing words only occurred when the subjects regressed or reread the text. The remaining question is whether the display changes themselves induced these regressions and rereadings. Table 2 indicates that in the data which were selected on having a display change during

the saccade prior to fixation F0, there was very little difference between the frequency of regressions in the experimental and control conditions on saccade S1. Furthermore, frequency distributions of the number of times that the critical word was fixated in the experimental and control conditions showed very little difference in the frequency of being fixated only once (104 vs. 111 respectively). The primary difference in these distributions was in the frequency with which the critical word received 3 or more fixations, which was 44 for the experimental condition (of which 13 instances showed 5-10 fixations) and 21 for the control (of which only 4 showed 5 or 6 fixations, none with more). Thus, it appears that the changing of the words did not induce the regressions and rereadings, but that, when a regression occurred, the fact that the word was sometimes now different tended to induce additional fixations in the control condition. These fixations tended to be longer in duration than fixations involved in regressions and rereading in the control condition.

It is concluded, then, that there is no evidence that the changing of the critical word from one fixation to another was having any detectable effect, either in producing longer fixations, shorter saccades, or a greater likelihood of regressing. When, for some reason other than the display change,

there was a regression or the critical word was refixated, did the discrepancy produced by the display change have an effect. Thus, there is no evidence that information about the first or fourth letters of the word (or word shape involving these letters) was acquired from the periphery on one fixation and then influenced the processing of the critical word on the next fixation, when it was brought into foveal vision.

Discussion

With respect to the hypotheses posed earlier, it seems clear that the perception of the words studied is best described by the word unit hypothesis. There was no evidence that sub-word units were being acquired on successive fixations and integrated into a single perception, nor that the visual information being manipulated in this study was being obtained peripherally from a word on one fixation and was then facilitating its perception on the next. Rather, the critical words were being perceived during only one fixation, that on which the word was directly fixated, and the changing of the letters only had an effect if the reader regressed or refixated the word for some reason.

These results are quite different than those obtained by Rayner (1975) and strongly challenge the notion that word

perception during one fixation is facilitated by information obtained peripherally during a prior fixation (McConkie & Rayner, 1976a; Patberg & Yonas, 1978; Rayner, 1978; Rayner, 1979b; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Smith, 1971). If information about the critical words was being acquired on prior fixations, that information must not include letter features, even for the initial letter of the word, or even word shape information, since word shape was changed in a number of the instances used in the study. If such information was being acquired, the present study found no evidence that it was being used to facilitate reading.

It is necessary, then, to consider why it was that the results of this study seem so contrary to prior theory and research. One possibility is that there was something peculiar about this study that inhibited the normal integrative processes during reading. This could be due either to the nature of the materials used or to the nature of the task. With regard to the materials, it should be noted that the critical word location was a relatively unconstrained word position. This was necessary in order for it to be capable of containing any of four different words, selected only on the basis of their having certain letter similarities. It may be that the acquisition and use of

peripheral visual information to facilitate later word recognition only occurs when there exists a higher level of contextual constraint (Haber, 1978; McClelland & O'Regan, 1981; Paap & Newsome, 1981). This is a possibility that requires further investigation. On the other hand, the task could be suspect as well, especially in the present study. Subjects were asked to read short texts consisting of one to three sentences, and then to select from among several visually similar word alternatives. It is possible that this could induce a sort of word-by-word consideration of the text that is different than the processing that takes place in more normal reading. Since all the subjects in this study had previously participated in a much larger study employing the same task, having read over 300 such texts, they may have developed a peculiar reading strategy. To test this, four naive subjects were tested in a somewhat different manner. After reading each passage, the subject came off the bite bar and answered an oral question which was designed to require more than a one-word answer, but with an answer that would reveal which of the words was perceived during reading. The data from these subjects were very much like those from the subjects in the main experiment. In particular, from texts read in the experimental condition there was only one instance (out of a total of 44) in which a subject reported having read a word

that was never presented. The control condition produced four such instances. Once again, there was no evidence for the sub-word unit hypothesis, and there was no other evidence for greater confusion or difficulty in responding to the words in the experimental condition. Thus, it seems unlikely that the results were due to the task employing a test which required subjects to select from among visually similar words.

Another possible reason for the discrepant results is that earlier conclusions may have been in error. All studies involving eye movement contingent display control which have been taken as evidence for the existence of facilitation from prior peripheral information have involved changing the display in some manner from one fixation to the next. In most, some stimulus pattern (erroneous letters or a grating) is present in the visual periphery on one fixation, but is removed or relocated on the next fixation, so that the part of the text now in the fovea and near-fovea is veridical. When this results in a detectable change in reading (increasing reading time, or causing specific changes in the eye movement pattern) it has been assumed that this was due, at least partially, to the peripheral visual information interfering with or not providing the normal facilitation of later foveal processing (McConkie, 1979; Rayner, 1979b).

However, it should be noted that these studies actually provide three separate possible sources of difficulty to reading. The first is the existence of inappropriate stimulus patterns in the periphery during a fixation. Underwood and McConkie (Note 1) have specifically explored the effects of having erroneous letters at different retinal locations, for instance. The second is the fact that the stimulus pattern on one fixation is somehow different than it had been on the prior fixation. The third is the fact that changes are occurring on the CRT which, by themselves, can have a disrupting effect on reading. While it has been demonstrated that briefly replacing text with other text or letter strings during a saccade has no effect on reading, it is also true that changes occurring during the first 30 msec of a fixation produce disruptive effects on reading (Wolverton, Note 2). Thus, it is extremely critical for this type of research that any display changes occur at a time when the stimulus movement associated with the change is not perceived. No study has yet been done which shows how late in the saccade, or how early in the fixation, these changes can be made without the simple existence of movement on the CRT having an effect on reading, and no study has employed an appropriate control condition for such an influence. Of course, the claim that peripheral visual information is being acquired and used to

facilitate later foveal perceptual processing is based on the assumption that some or all of the observed effects of display changes in the relevant studies have arisen from the second influence, non-identical stimulus patterns on successive fixations, rather than from either of the others.

All but three studies which have involved reading of continuous text have also used text-inappropriate peripheral visual patterns, either words spelled backwards (O'Regan, 1980), other letters substituted for text original letters (McConkie & Rayner, 1975; McConkie & Rayner, 1976b; Rayner, 1975; Underwood & McConkie, Note 1), or gratings (Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner & Pollatsek, Note 3). Thus it is possible that in all such studies the changes in reading which were observed resulted from the presence of inappropriate peripheral visual patterns themselves, rather than from the existence of change in the pattern from one fixation to the next.

The two studies in which this was not the case, other than the present one, were by Rayner (1974) and McConkie (Note 5). In the Rayner study, there was one condition (condition W-SL) in which the contents of one word location was changed from one word to a second during the saccade which took the eyes to that word.

Both words were appropriate in the context, and they had the same initial and final letters and the same general word shape. The present study would seem to have produced a potentially more noticeable change, since the initial letter was changed, and in many of the instances the word shape was changed as well. Still, Rayner found an effect of his manipulation, an increase of about 20 msec. in the immediately following fixation duration, whereas the present study found no effect. It is possible that the effect in the Rayner study was actually due to the third type of influence, detection of movement in the display associated with the making of the change. Several analyses were conducted to consider this possibility at the time the study was done (Rayner, Note 5) and all but one yielded nonsignificant results. However, a reconsideration of the data presented indicates that, while the differences were not large, most were in the direction suggested by the hypothesis that changes were indeed being seen. For instance, when fixations were divided into those which occurred on the letter following the boundary which triggered the display change (and thus had the greatest possibility for the change occurring after the saccade was completed) vs. fixations further from the boundary (and hence which provided greater saccade time after a change was called for), only one of five tests was significant, but four of the five showed longer fixations in the

first case than in the second. The average difference between the means of these five comparisons was greater than the 20 msec. difference found for the experimental manipulation in the study. In contrast to this study, where display changes could be triggered late in the saccade and thus may not be complete until the eyes were actually in fixation, both the present and a former study (McConkie, Note 4) only made changes early in the saccade. McConkie (Note 4) caused a single letter to change during each saccade, alternating the contents of a critical location between two words, both of which were contextually appropriate. In the present study two letters were changed. In both studies the change occurred about 8 msec after the onset of the saccade, and since it required only 3 msec, it was completed long before the end of the saccade, which lasted at least 20 msec. Neither of these studies provided any evidence that changing a word from one fixation to the next had any effect on reading, unless the reader later reread the word. Thus, it may be that where effects of changing words or letters from one fixation to the next have been observed in the reading of continuous text, these were due to the presence of erroneous or inappropriate peripheral patterns during fixations, or to perceived movement of the text when changes occurred late in saccades or early in fixations, rather than to the mismatch of visual patterns from one fixation to the next.

The present results seem particularly damaging to two proposals concerning the use of peripheral information which have been put forth. Bouma (1978) suggested that information from the periphery is transmitted to the brain much slower than foveal information, and that in a series of fixations during reading the peripherally-obtained information from a word and the later foveally-obtained information from the same word arrive at appropriate brain centers at about the same time, thus supporting one another and facilitating the perception of that word. Smith (1971) proposed that the region within which words are read is sufficiently large that the same word is actually read on several fixations, thus facilitating processing and providing redundancy against misreadings. It seems clear that neither of these proposals describes the perception of the words studied in the present experiment. Rather, the evidence indicates that the words were read from information obtained during only one fixation.

Even if peripheral information is not being used to facilitate later foveal perception, this is not to say that peripheral information is not useful during reading. Other studies indicate that sometimes words not directly fixated are still being read (Hogaboam, Note 6; Kliegl, Olson, & Davidson, Note 7) and that lengths of words in the periphery, quite apart

from their other characteristics, can influence where the eyes are sent on a saccade (O'Regan, 1980). However, these are characteristics of the stimulus that are available peripherally from the present fixation, and do not require integration across fixations. If some type of information is being carried across fixations in reading, its nature is not presently apparent. The carry-over of strictly visual aspects of letters and word shapes does not seem to occur (McConkie & Zola, 1979) and the present study seems to eliminate the carryover of specific letters or semantic information. The fact that changing words has no effect eliminates the possibility of semantic priming based on peripheral patterns (Inhoff & Rayner, 1980). In summary, then, these results argue that reading is based on available retinal information rather than on patterns perceived during prior fixations. Whether good readers are more adept at using available peripheral information (Fisher, 1976; Patberg & Yonas, 1978) or not (Underwood, Note 8) is still a matter requiring investigation.

The results of this study also argue that the region within which visual information is used for word identification during a fixation is defined in terms of word units, not a specific number of letters to left and right of the fixation (McConkie, in press). While there has been prior evidence that this is so to

the left of the fixation point (Rayner, Well, & Pollatsek, 1980) the same is not true for the region to the right (Underwood & McConkie, Note 1). For instance, these last investigators found that when letters beyond the third to the right of the fixation point were replaced by other letters, the disruptive effect was just as great when this manipulation did not cause a change in the fixated word as when it did. The same was true when all letters beyond the fifth to the right were replaced. Thus, there was no evidence that errors were not being perceived when they lay outside the fixated word, or that this occurred less frequently or had less of an effect. Combining those results with the present study raises an interesting question. Is it possible that during a fixation the reader responds to orthographic irregularities in a word which is not identified on that fixation, and yet at the same time information perceived from such a word is not used in its perception when it is brought into the fovea on the next fixation? Since the present data are insufficient to answer this question, it must remain a topic for future investigation. If the answer is positive, this will be strong evidence that orthographic structure is perceived directly in reading, rather than only becoming important in lexical access (Underwood & McConkie, Note 1).

Finally, the results from the present study bear directly on the issue of how best to derive a measure of processing time in reading from eye movement data. One basic question has been whether perception during a fixation should be considered to be in letter or letter-group units (McConkie, Hogaboam, Wolverton, Zola, & Lucas, 1979) or word units (Just & Carpenter, 1980; Hogaboam & McConkie, 1981). The present results clearly favor the latter, and are in harmony with Just and Carpenter's "Eye-mind Assumption", though other evidence indicates that words other than that fixated are at times read during a fixation (Hogaboam & McConkie, 1981; Kliegl, Olson, & Davidson, Note 9). Apparently, at least when a person is reading carefully, five-letter words which are relatively unconstrained are read only when directly fixated.

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Appendix

1. As Kevin approached his grandfather's bungalo down the long country lane, he was taken aback by its /weedy/weepy/seedy/seepy/ appearance and its need for a coat of paint.

2. Ruth's great aunt is definitely the most /mushy/musty/gushy/gusty/ person she has ever met.

3. Dr. Koppof was able to demonstrate that the /blare/blame/flare/flame/ which had been so disconcerting to the natives of the region originated from a neighboring tribe.

4. With considerable hesitation, Phil asked Sue to /trade/trace/grade/grace/ his table, not knowing what the outcome might be.

5. English teachers typically believe that formal writing has the ability to clean out the /musty/musky/dusty/dusky/ reaches of the mind and that it contributes to clear thinking.

6. The second grader was doing very well in the spelling bee until he was given the word '/couch/cough/touch/tough/', which he missed by a single letter.

7. Mr. Gilmore has written a book in which he classifies /peaks/pears/beaks/bears/ from around the world. However, it will never be a best seller.

8. They have interesting /meals/meats/seals/seats/ at the Emporium. You really should make a visit there the next time you are in the city.

9. While the old herder shivered in front of his pot-bellied stove, he was lead to contemplate the results of his actions. While having his /goats/goals/coats/coals/ high seemed like a good idea at the time, he now realized the disadvantages.

10. Mr. Blackwell was, in order, an industrialist, a runner, a collector and a hypochondriac. The many /pills/piles/mills/miles/ he had accumulated over the years were often the topic of conversation among his friends.

11. The Recreation Housing Committee reported that five /teams/tears/beams/bears/ were recently discovered that we previously did not know about. Boyd has been assigned to seek more information and to report back to the Committee.

12. The high point of the Great Zaslow's act is when he /leads/leaps/heads/heaps/ all twenty tigers toward the gate of the cage at once.

13. It has been whispered that deaf Talu /beats/bears/heats/hears/ his chickens in the large bamboo cage.

14. In this particular form of treatment, the physician /seats/seals/heats/heals/ the injured bone directly in the socket.

15. Rosslyn decided that her husband's music and his /feats/fears/beats/bears/ were no longer tolerable and it was finally time for her to leave.

16. The children rang the school bell as the old teacher shopped at the fruit market next door. "Although I love the /dears/deals/pears/peals/," she said mournfully, "I can't take any more of them for a few days."

17. Everyone knows about the /raids/rails/maids/mails/ in my country, but the government is unable to do anything about them.

18. It has been said that a highly trained dog /heels/heeds/feels/feeds/ well only at the call of its master.

19. The old peddler had so many /warts/wares/carts/cares/ that it was hard for him to exert enough energy to make his way along the streets of the city.

20. After a careful examination of the Frenchman's /works/words/corks/cords/ the judges declared him to be the winner.

21. The officer inspected the /belts/bells/welts/wells/ before having his supper.

22. After hours of searching for them, the old /deans/dears/beans/bears/ were found in the park.

23. As the moon slid behind the clouds, the /yards/yarns/bards/barns/ had a strange effect on him.

24. The anthropologist, Dr. Barter, claimed that, unlike the compassionate and helpful Samoans, an Eskimo fisherman never /baits/bails/waits/wails/ for anyone, even his closest friends.

25. Yesterday afternoon Mr. Johns showed his /warts/wares/harts/hares/ to his friends.

Table 1

Responses Given to Test Word

Response Type	Frequency	
	Control Texts	Experimental Texts
Correct Response	170	161
Single Correct Response	170	156
Two Correct Responses	NA*	5
Errors	30	39
No Response	7	8
Single Erroneous Response	12	17
Multiple Words, Including Correct Response	11	13
Multiple Words, Not Including Correct Response	0	1
Total	200	200

* NA = Not applicable.

Table 2

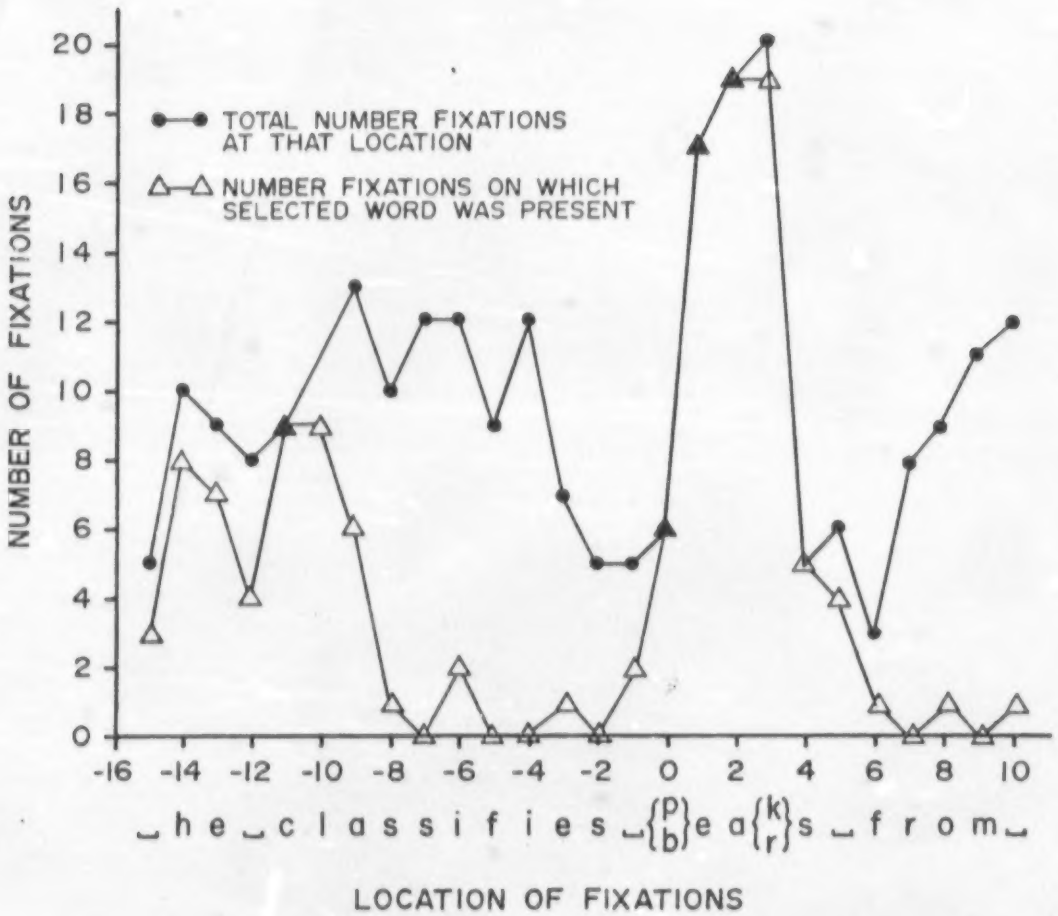
Eye Movement Data Following Display Change Prior to Fixation F0

Data	Condition		t	d.f.	p
	Experimental	Control			
No. instances	157	151			
F0 fixation duration	283 msec	273 msec	.79		
S1 forward saccade length	7.16 cp*	6.96 cp	1.07		
No. regressive S1 saccades	26	20			
F1 fixation duration	275 msec	254 msec	1.43	15	$p<.09$
F1 fixation duration when not on critical word	267 msec	264 msec	<1		
F1 fixation duration when S1 is not regressive	261 msec	261 msec	<1		
F1 fixation duration when F1 is right of the word	268 msec	274 msec	<1		
F1 fixation duration when F1 is left of or on word	281 msec	214 msec	2.88	15	$p<.005$

*cp = Number of character positions, where 3 cp equal 1° of visual angle.

Figure Caption

Figure 1. Number of fixations at each letter position with respect to the critical word location, and the number of these on which the word selected as having been seen was present during that fixation. Only data from instances in which the subject did not regress back into this region, and in which the subject responded correctly on the test, are included.


20
18
16
14
12
10
8
6
4
2
0
NUMBER OF FIXATIONS
TOTAL NUMBER FIXATIONS AT THAT LOCATION
NUMBER FIXATIONS ON WHICH SELECTED WORD WAS PRESENT
-16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10
␣ h e ␣ c l a s s i f i e s ␣ {p b} e a {k r} s ␣ f r o m ␣
LOCATION OF FIXATIONS